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# Characterizing Digital Dashboards for Smart Production Logistics

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**Abstract.** Developing digital dashboards (DD) that support staff in monitoring, identifying anomalies, and facilitating corrective actions are decisive for achieving the benefits of Smart Production Logistics (SPL). However, existing literature about SPL has not sufficiently investigated the characteristics of DD allowing staff to enhance operational performance. This conceptual study identifies the characteristics of DD in SPL for enhancing operational performance of material handling. The study presents preliminary findings from an ongoing laboratory development, and identifies six characteristics of DD. These include monitoring, analysis, prediction, identification, recommendation, and control. The study discusses the implications of these characteristics when applied to energy consumption, makespan, on-time delivery, and status for material handling. The study proposes the prototype of a DD in a laboratory environment involving Autonomous Mobile Robots.

**Keywords:** Digital dashboards · Smart Production Logistics · Autonomous Mobile Robots.

## 1 Introduction

Smart Production Logistics (SPL) is critical for enhancing the operational performance and increasing the competitiveness of manufacturing companies [3]. SPL refers to applying the Industrial Internet of Things (IIoT) and digital technologies (e.g., cyber physical systems, artificial intelligence, or digital twins) for achieving the active perception, response, and autonomous decisions regarding the movement of information and materials in a factory [1]. SPL presents several benefits to manufacturing companies including the timely and automatic

identification of exceptions, self-organizing configuration and self-adaptive collaboration of resources [2].

Presenting information to staff with the purpose of monitoring, identifying anomalies, and facilitating corrective actions is decisive for achieving the benefits of SPL [4]. This need originates from the increasing level of automation facilitated by the implementation of digital technologies, and improving the work and conditions of humans at manufacturing companies [5]. Therefore, interacting with and presenting information to staff for enhancing operational performance is complementary to existing research efforts in SPL. For example, recent studies describe the importance of integrating monitoring systems that collect data in real-time, and predictive analytics that examine the performance of production logistics [6]. Additionally, the literature identifies the need for interfaces where humans can directly take decisions about strategies, control, or activities in production logistics [7].

The purpose of this conceptual study is to identify the characteristics of DD in SPL for enhancing operational performance of material handling. The study presents preliminary findings from an ongoing laboratory development. To achieve this purpose, the study applies the concept of DD according to [20], and discusses six characteristics for enhancing operational performance in material handling. These include monitoring, analysis, prediction, identification, recommendation, and control. Then, the study describes the implications of the six characteristics of DD for addressing energy consumption, makespan, on-time delivery, and status of resources in material handling. Finally, we propose a prototype of DD in a laboratory environment involving Autonomous Mobile Robots (AMRs) in material handling. The remainder of this study includes the following structure. Section 2 presents related works involving SPL and DD. Section 3 discusses the implications of DD in SPL. Section 4 proposes a prototype of a DD for enhancing operational performance in a laboratory environment. Section 5 concludes this study.

## 2 Related works

### 2.1 Operational performance in smart production logistics

The implementation of digital technologies in SPL has critical implications for monitoring and interacting with resources enhancing the operational performance of material handling. SPL includes the use of IIoT with the purpose of connecting all industrial resources (e.g., machines and control systems) with information systems for understanding the flow of materials in factories [2]. This facilitates the real-time acquisition of data necessary for increasing material visibility [9], and the development of services for monitoring, controlling, optimizing, and making autonomous decisions that identify anomalies and facilitate corrective actions [16]. Taken together, these advances are critical for realizing dynamic and customer-oriented activities supporting the goals of logistics (e.g., right time, delivery, quality, and cost) [10].

In this study we give precedence to four salient concerns for enhancing operational performance in SPL according to recent research efforts [2]. These include energy consumption, on time delivery, makespan, and status of resources. For example, [11] monitor the status of Automated Guided Vehicles (AGVs) for planning and scheduling problems with the use of Cyber Physical Systems (CPS). [12] monitor the energy consumption and on-time delivery of AGVs when applying a proactive material handling method for a CPS enabled shop floor. [2] focus on waiting time, makespan, and energy consumption during a self-adaptive collaborative control mode for material handling in SPL. [14] monitor energy consumption, on time delivery, and deviations in process cycle times when developing a decision support system capable for shop-floor decision-making activities. [14] target energy consumption, delivery, and makespan when developing a real-time production and logistics self-adaptation scheduling.

IIoT is a critical aspect for monitoring and interacting with resources in SPL including AGVs or autonomous mobile robots (AMRs). IIoT facilitates sensing data, processing information, and realizing services [16]. Recent research efforts suggest applying an IIoT architecture including a sensing, networking, and applications layer for monitoring and interacting with resources in material handling [1]. The sensing layer comprehends all physical resources responsible for material handling (e.g., parts, AMRs, or pallets) and IIoT devices generating data about the location or status of equipment. The networking layer involves the real-time capture of data, its processing into information, and transfer to databases or applications. Finally, the applications layer contains service that establish links with the enterprise tier that implements domain-specific applications and provides end-user interfaces. Applying a similar IIoT architecture, [13] suggest measuring resource consumption in production processes, using open source tools for data collection (Node-Red), storing (InfluxDB) data and visualization (Grafana) information. The study addresses issues such as hardware and software compatibility, and allows for a customizable and scalable architecture.

## 2.2 Digital dashboards supporting operational performance

DD include visual applications that summarize information aligning the goals and processes of organizations, and help users take and improve decisions [20]. DD involve multiple coordinated visualizations and interactive features for rapid understanding. Its benefits include increased communication, transparency and agility, and understanding of process context, performance, and remedial actions [18].

DD for enhancing operational performance target frontline workers, and address the identification of problems and their corrective actions [22]. Accordingly, recent research efforts on DD underscore the importance of proactively supporting and improving decisions of staff at an operational level. For example, [3] proposes a digital twin framework including a DD for the real-time monitoring of machines and interconnected system for with the purpose of improving overall equipment effectiveness and order scheduling. [19] present a CPS including a

dashboard displaying the real-time status of a production system providing staff with tools for supervision and intervention in case of failure.

This study applies the six characteristics of DD for enhancing operational performance identified by [20] including monitoring, analysis, prediction, identification, recommendation, and control. This choice is informed by the recency of these findings, and the need for efficiently providing information to productive areas and feeding DD with adequate data sources. Monitoring refers to the intuitive display of information and associated activities for staff responsible for operational performance [20], which is essential for triggering alerts in reduced performance. [22]. Identification comprehends activities determining the root cause of problems in operational performance [21]. Analysis involves the examination of relevant information to demonstrate the consistency and effectiveness of resources or processes [20]. Recommendations focus on transmitting information about strategic objectives and enable staff and resources to measure, monitor, and manage key activities and processes [18]. Communication concerns the transmission of information about strategic objectives, and enable staff and resources to measure, monitor, and manage key activities and processes. For example, [3] suggest the use of digital technologies including IIoT or digital twins for achieving real-time prediction of expected behavior, recommendations of actions, and communication with resources for enhancing operational performance. Control consists of the interaction between systems for regulating and promoting activities for dealing with non-conforming problems.

### 3 Implications of digital dashboards in smart production logistics

The purpose of this conceptual study is to identify the characteristics of DD in SPL for enhancing operational performance of material handling. This section discusses the implications of the six characteristics of DD (e.g., monitoring, analysis, prediction, identification, recommendation, and control) on energy consumption, makespan, on-time-delivery, and status of resources.

The literature underscores the importance of reducing energy consumption in material handling leading to improved sustainability [11]. For example, [13] suggests an IIoT architecture including a dashboard solution, visualizing the environmental footprint of production to help users understand resource patterns and improve eco-efficiency of processes. DD can contribute to this goal in a number of ways. For example by monitoring the energy consumption of one or a fleet of AMRs during a period (e.g., electricity in kilowatts per hour). Analyzing historical trends, informing, or alerting staff about failure to achieve goals of energy consumption. Predicting and presenting recommendations for meeting energy consumption goals in the following period according to historical data (e.g., energy management and control policies, vehicle charging, or execution of material handling operations). Presenting information to staff about strategic goals of energy consumption, and controlling resources in material handling with the purpose of achieving these goals.

Traditional measurements of operational performance in production logistics remain decisive for securing manufacturing competitiveness [3], [14], [15]. To this extent, the use of DD in SPL has important implications for makespan, on-time delivery, and resource utilization. For example, DD provide benefits to makespan by monitoring the current and historical patterns involving the maximum time to complete tasks in material handling. Further, DD may facilitate identifying tasks, stations, or AMRs contributing to an extended makespan. Additionally, these can present information to staff including predictions of makespan considering current resources and material handling tasks, or provide recommendations such as the need for additional resources for meeting goals in makespan. Finally, DD may facilitate the control of resources in material handling such as a change of speed in AMRs or preference for routes.

DD present distinct benefits for on-time delivery of material handling in SPL. In relation to monitoring, DD help determine the status of delivery tasks including their on-time or late delivery. Also, they can provide time series analysis of on-time delivery percentage for a period and its comparison with established goals. Furthermore, DD can present critical information to staff including the identification of the root cause of problems for late delivery (e.g., changes to production schedule, production problems, failed equipment, or poor quality).

The use of DD contributes to improving the use of resources in material handling including AMRs. This can reveal their real-time movement and status including idle, loading and unloading, moving with and without products, charging or failure times. Furthermore, DD are decisive for aggregating historically this information and identifying failed performance (e.g., excessive movement without products). Finally, DD are crucial for communicating expected goals on the use of resources or executing missions for an AMR with the purpose of controlling behavior (e.g., assigning a resource to an area).

## 4 Proposed digital dashboard for enhancing operational performance

This section proposes a prototype of a DD for enhancing operational performance in a laboratory environment involving AMRs. The features of the DD that make it applicable to the case of AMRs include the need from staff for understanding dynamic resources and monitoring and controlling remotely operations of this equipment [23]. Fig.1 presents the proposed prototype of a DD for enhancing operational performance involving AMRs.

The case involves the picking and delivering of parts in the machining area of an automotive manufacturer. Material handling includes the delivery of supplies from a warehouse to machining stations and transfer of work-in-progress parts and finished products. Management will implement AMRs and IIoT devices with the purpose of increasing visibility in material handling and enhancing operational performance. Accordingly, there is a need for monitoring the energy consumption, makespan, on-time delivery, and status of the AMRs. The prototype application utilizes a three-layered IIoT architecture according to the In-

ternational Electrotechnical Commission (2016) [1, 13]. These include perception, networking, and application layers for achieving real-time collection of data, and active perception and response of resources.

The perception layer includes physical resources and IIoT devices in material handling. Physical resources comprehend products, pallets, buffers, or storage units. IIoT devices involve sensors and actuators capable of transmitting data and receiving information to execute actions. This involves the use of pallets for transporting products, and radio frequency identification devices for identifying the position of resources, and an AMR for executing material handling tasks in the prototype application. Input data includes three aspects. First, a schedule including a description of tasks for material handling. Second, the layout delimiting the activity of the AMR. Third, data collected from the AMR with application programming interfaces including the position, energy consumption, and speed.

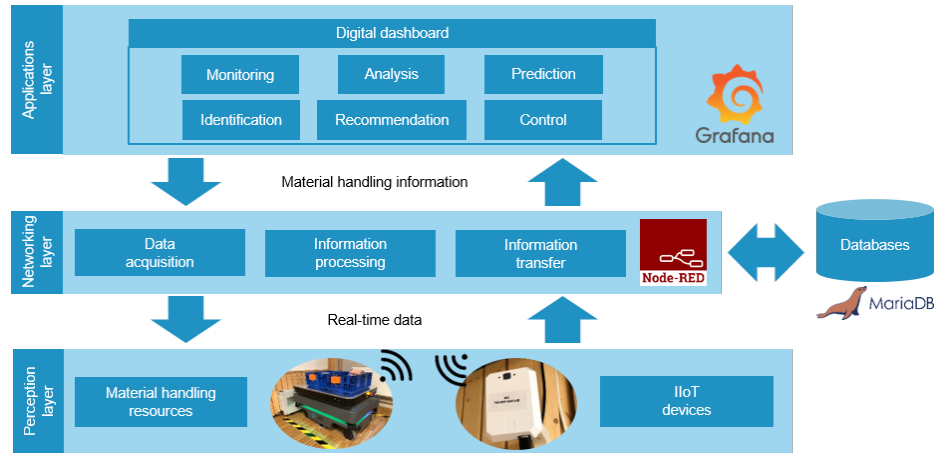
The networking layer establishes the communication between the physical world and digital applications including those necessary for achieving the characteristics of a DD. This layer captures data, and processes data into information, and transfers information to achieve material handling tasks, and coordinated visualizations and interactive features for rapid understanding. The prototype application applies Node-RED as a middleware for connecting hardware devices, application programming interfaces, and online services. Additionally, the database management system MariaDB stores information generated during material handling including the energy consumption, orders in material handling, AMR missions, and results from makespan, on-time delivery, and AMR status.

The applications layer provides personalized services according to the needs of staff. Therefore, this layer contains the applications realizing a DD for enhancing operational performance in material handling. The prototype application applies the multi-platform open source analytics and interactive visualization application Grafana in this layer. The DD utilizes data sources facilitated by the networking layer for visualizing operational performance.

## 5 Conclusions

This conceptual study identified the characteristics of digital dashboards in SPL for enhancing operational performance of material handling. The study discussed the implications of the six characteristics of DD (e.g., monitoring, analysis, prediction, identification, recommendation, and control) on energy consumption, makespan, on-time-delivery, and status of resources in material handling. The study proposed prototype of a DD for enhancing operational performance in a laboratory environment including AMRs. Future research will focus on two aspects. First, presenting empirical results about the implications of DD in operational performance of material handling. Second, proposing a data model for transferring information across layers in an IIoT architecture for securing DD.





**Fig. 1.** Proposed prototype of a DD for enhancing operational performance involving AMRs.

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